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CAPACITORS ADAPTED FOR ACOUSTIC RESONANCE CANCELLATION

BACKGROUND OF THE INVENTION

Varactors are voltage tunable capacitors in which the capacitance is dependent on a voltage applied thereto. Although not limited in this respect, this property has applications in electrically tuning radio frequency (RF) circuits, such as filters, phase shifters, and so on. The most commonly used varactor is a semiconductor diode varactor, which has the advantages of high tunability and low tuning voltage, but suffers low Q, low power handling capability, high nonlinearity and limited capacitance range. A new type of varactor is a ferroelectric varactor in which the capacitance is tuned by varying the dielectric constant of a ferroelectric material by changing the bias voltage. Ferroelectric varactors have high Q, high power handling capacity, good linearity and high capacitance range.

The use of barium titanate, strontium titanate, or barium strontium titanate (BST) of any composition including any doped BST formulation to make tunable capacitors relies on the dielectric properties of the ferroelectric material in the paraelectric phase. This means the dielectric constant of the material changes under the applied electric field. As a capacitor, the capacitance at zero bias is a maximum and the capacitance drops with applied voltage as illustrated in FIG. 1 at 100 in capacitance 110 vs. volts 120. This change in capacitance allows these units to be used to create tunable circuits in filters, matching networks, resonant circuits and other applications at frequencies from audio to RF and microwave.

The cross section of a typical capacitor consists of two (or more) conductive plates or electrodes with one or more layers of tunable dielectric material such as BST between them. The dielectric constant of the tunable material determines the capacitance as $C = \epsilon A/d$, where ϵ is the dielectric constant of the tunable material, A is the area of the electrodes and d is the separation of the electrodes and thickness of the tunable material. A DC voltage is applied to the electrodes to induce an electric field in the tunable dielectric.

Since ϵ of the tunable material is a function of the electric field which is $E = V/d$, then $V = Ed$ and thus the capacitance is a function of voltage. However, ferroelectric materials are also electrostrictive. As an electric field is applied, which lowers the dielectric constant, the piezoelectric constant of the material becomes non-zero. As a result, the electric field is converted into a physical change of the lattice constants of the film. Simultaneous application of an AC signal to the material causes acoustic vibrations of atoms in the crystalline lattice and is called electromechanical coupling. Therefore any AC signal on the tunable capacitor under bias produces an acoustic response. At certain frequencies, determined by the layer thicknesses and materials in the capacitor stack, the acoustic response of the structure will be resonant and the loss of the capacitor will increase as energy is lost from the AC electrical signal into acoustic vibrations.

This effect manifests itself as regions or frequencies where capacitors exhibit high losses. Much design effort must be used to choose the layer materials and their thicknesses to minimize or eliminate the acoustic losses at the desired frequencies of operation; however, it may be impossible to completely eliminate the losses within the desired frequency band(s) because of conflicting performance requirements for the device. This effect manifests over a wide range of frequencies up to many Gigahertz—which is the usual range of frequencies used by applications for these devices.

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To illustrate this effect, an example of the frequency response of the Q-factor of a tunable capacitor from 100 MHz to 3 GHz is shown on FIG. 2, generally as 200 [Q is a measure of the loss of the capacitor defined as $Q = X_c/R_s$ where $X_c = 1/\omega C$ and R_s is the series resistance].

At zero applied voltage 205, there is no generation of acoustic vibrations by the tunable material and the Q versus frequency is relatively smooth from 100 MHz to 3 GHz and rolls off from about 180 down to 35.

At 30 volts applied voltage 215, this capacitor was designed to avoid acoustic loss effects up to about 1 GHz and the response is again fairly smooth and flat dropping from about 150 to 70. Above 1 GHz, however, the response is no longer flat and the Q drops well below the Q at zero bias. The center frequency of the major resonances due to the acoustic coupling are noted on the chart at about 1.5 GHz (220), 1.7 GHz (225), 1.85 GHz (230) and 2.8 GHz (235). These resonances prevent the capacitor from being used in those frequency ranges.

Thus, there is a strong need for voltage tunable capacitors adapted to reduce acoustic losses and improve Q.

SUMMARY OF THE INVENTION

An embodiment of the present invention provides a device, comprising a multilayered tunable dielectric capacitor, wherein the multilayers of tunable dielectric are adapted to be DC biased to reduce the dielectric constant; and wherein the DC bias is arranged so that the number of layers of tunable dielectric biased positively is equal to the number of layers of tunable dielectric biased negatively.

An embodiment of the invention further provides a method, comprising reducing the losses due to electro-mechanical coupling and improving Q in a multilayered capacitor by placing a first capacitor layer adjacent at least one additional capacitor layer and sharing a common electrode in between the two such that the acoustic vibration of the first layer is coupled to an anti-phase acoustic vibration of the at least one additional layer.

Still another embodiment of the present invention provides a multilayered tunable capacitor, comprising a first voltage tunable dielectric layer, at least one additional voltage tunable dielectric layer adjacent to the first voltage tunable dielectric layer and sharing a common electrode in between the two, and wherein any acoustic vibration of the first voltage tunable dielectric layer caused by the application of combined AC and DC voltages is coupled to a corresponding acoustic vibration caused by the application of the combined AC and DC voltages to the at least one additional voltage tunable dielectric layer, thereby reducing acoustic losses and improving Q.

Yet another embodiment of the present invention provides, a device, comprising a single layered varactor consisting of at least two capacitors connected in series to an RF signal and adapted to reduce acoustic losses and improve Q. The adjacent electrodes of the at least two capacitors may be positioned to vibrate in opposite phases thereby reducing acoustic losses and improving Q. Further, a DC bias may be applied across the at least two capacitors from a top to a bottom electrode.

Yet another embodiment of the present invention provides a method, comprising reducing the acoustic losses and improving Q in a single layered varactor by connecting at least two capacitors in series to an RF signal so that adjacent electrodes of the at least two capacitors vibrate in opposite phase. In the present method, the DC bias may be applied across the at least two capacitors from a top to a bottom electrode and the at least two capacitors may produce acoustic